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The ANDES system can be configured to process digital or digitized NDE data from any source. The system will analyze the data for anomalies classify anomalies, and make a recommendation on the serviceability pf the component containing the anomalies based on established criteria. The ANDES system at Hill AFB is configured to process X-ray computed tomography (CT) images in support of the surveillance activities on the Minuteman III third stage solid rocket motors. The system functions as a supplement to the visual image analysis effort and as an automated report generation and electronic report storage device.

The ANDES system installed at Kelly AFB also processes CT images. The components which are supported are the oil scavenge assembly from the F-1000 aircraft engine, the yoke pivot block casting for T-38 aircraft, and the torpedo housing casting Kelly AFB inspects for the NAVY. The ANDES system screens the casting data images for void content and cracks and a braised joint on the oil scavenge tube for leak paths and total wetted area.

This paper presents the development history, the system design issues, the system hardware and software architectures employed at both Hill AFB and Kelly AFB, and a brief description of the performance of the operational systems.

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Application of automated NDE data evaluation to missile and aircraft systems

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As part of the Advanced Launch System technology development effort begun in 1989, the Air Force initiated a program to automate to the extent possible the processing of NDE data from the inspection of solid rocket motors during fabrication. The computerized system, called the Automated NDE Data Evaluation System or ANDES, was developed under contract to Martin Marietta. The generic ANDES system has been tailored to support inspection tasks at two Air Logistic Centers in the Air Force. These centers are the Ogden Air Logistic Center at Hill AFB, UT and the San Antonio Air Logistic Center at Kelly AFB, TX.

The ANDES system can be configured to process digital or digitized NDE data from any source. The system will analyze the data for anomalies, classify detected anomalies, and make a recommendation on the serviceability of the component containing the anomalies based on established criteria. The ANDES system at Hill AFB is configured to process X-ray computed tomography (CT) images in support of the surveillance activities on the Minuteman III third stage solid rocket motors. The system functions as a supplement to the visual image analysis effort and as an automated report generation and electronic report storage device.

The ANDES system installed at Kelly AFB also processes CT images. The components which are supported are the oil scavenge assembly from the F-100 aircraft engine, the yoke pivot block casting for T-38 aircraft, and a torpedo housing casting Kelly AFB inspects for the NAVY. The ANDES system screens the casting data images for void content and cracks and a braised joint on the oil scavenge tube for leak paths and total wetted area.

The paper will briefly discuss the ANDES development history, the system hardware and software architectures employed at both Hill AFB and Kelly AFB, and a brief description of the performance of the operational systems.

Keywords: automated NDE processing, NDE, aging, solid rocket motors, computed tomography

1. INTRODUCTION

The Air Force has invested significantly in inspection technology in the past 20 years. The investment supporting the rocket propulsion mission has been mainly in the implementation or development of data acquisition technology. Although, some data processing technology was also implemented with all of the data acquisition development, the assessment of the components being inspected is still based on visual interpretation of the NDE data. A joint R&D effort between NASA and the Air Force was undertaken in 1989 to develop a new generation of launch vehicles. This effort was called the Advanced Launch System, ALS, later renamed the National Launch System, NLS. The goal was to reduce the cost of placing a payload in low earth orbit by an order of magnitude, to $300 per pound. The Air Force managed a technology program for ALS named NDE for Solid Rocket Boosters (NDE for SRB's). The goal of the program was to totally automate the NDE data processing and decision processing for the in-process and end item acceptance during the manufacture of the solid rocket boosters for the ALS effort. This project was not completed as originally planned due to cancellation of the ALS effort, but the contract did deliver two operational systems with reduced capabilities.

2. PROJECT HISTORY

The NDE for Solid Rocket Boosters program was conceived as a $12M effort consisting of four phases spanning five years. The program was to conclude with the delivery of a production ready system to support the fabrication of the solid rocket booster design being developed in other ALS projects. The tasks in the first phase of the program were to develop the operational requirements, develop the functional design of the automated system, to generate hardware and software

architectures to be incrementally developed in the subsequent three phases, and to define the test and validation plan to demonstrate that the system performed properly. The automated system was called the Automated NDE Data Evaluation System, or ANDES. Although it was to be developed for ALS, from the program's beginning, the plan was to build ANDES as generic and as flexible as possible.

In the second year, the ALS funding was cut dramatically. In the third year, most of the ALS programs were ended. The NDE for SRB's effort was early in phase two, finalizing the system design and beginning to write software. The program was reorganized to deliver a functioning prototype system on the remaining contract funds. While preparing to end the effort, the Air Force searched for other benefactors to continue the development. Two were found, Kelly AFB and Hill AFB. A new task in the NDE for SRB's contract was added in the third quarter of FY 91 for the Science and Engineering Laboratory at Kelly AFB. This task was to deliver an operational version of ANDES to process X-ray CT images for several miscellaneous components the Lab was fabricating or refurbishing. In the third quarter of FY 92 another task was added to develop an ANDES system which would process X-ray CT images on Minuteman third stage solid rocket motors at Hill AFB. These added tasks permitted the program to extend the development of ANDES into operational systems. These two systems do not have all of the functional capabilities intended in the original ALS design, but they do contain the fundamental operational capabilities, plus the software and hardware architecture of the original system design.

3. ANDES DESIGN FOR ALS

The original ANDES design for ALS supported all the various functions for the fabrication of a solid rocket motor. Figure 1 shows a top level functional diagram of the ANDES system as it was designed. The two ovals represent the two

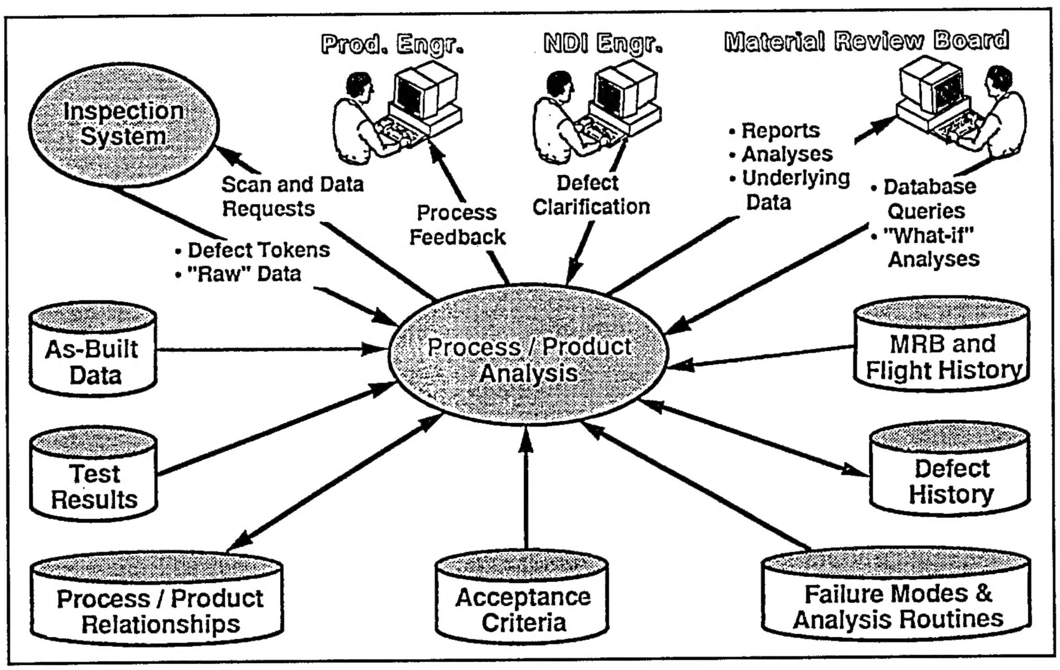

Figure 1. Functional Diagram of ANDES Software.

major software modules, the seven cylinders represent various classes of information to be stored in the system data base, and the computer terminals represent three of the user interfaces with the system. The arrows depict the directions of information flow. The Inspection System (IS) module is the interface to a NDE data acquisition system. This figure shows only one of these modules, however, ANDES was designed to service multiple acquisition systems simultaneously. The actual system would have a tailored IS module for each acquisition system that is connected. What is not apparent from this figure is how the software system is configured and managed from a global standpoint. The main user interface for setup, maintenance, and overall system management is implemented as part of the Process / Product Analysis (PPA) module. The hardware architecture used for the ANDES system was chosen primarily due to the operational requirements dictated by the fabrication process layout, several locations widely separated in distance. This required a system with several workstations connected on

a local area network. The data storage and data processing would be distributed among the various workstations.

Figure 1 makes reference to the term "defect token" which needs to be defined here. In figure 1, the arrow from the Inspection System oval to the Process / Product Analysis oval is labeled with two types of data, defect tokens and raw data. Defect tokens are small packets of text information which describe the characteristics of a detected feature, see figure 2. The approach of "tokenizing" the information about a detected feature was adopted in order to minimize the amount of data being permanently stored and shared between processes.

```
Token:
    {
     class: propellant
     radial_center: 151.019318
     angular_center: 153.066589
     major_extent_mm: 9.614274
     major_extent_deg: 3.167152
     minor_extent_mm: 6.342917
     radial_extent: 4.267532
     orientation: 85.215927
     area: 36.944504
     rel_amplitude: 0.874997
     min_dist_to_bore: 0.154984
     max_dist_to_bore: 4.422516
     min_dist_to_ins: 128.180756
     max_dist_to_ins: 133.870804
    },
```

```
Typed Anomaly:

 2: gouge - accept.  PSC Script used: 3RDG.gouge.any (New)
  angle center:        153.07 deg.;   major extent:          9.61 mm;
  radial center:        151.02 mm;   radial extent:          4.27 mm;
  minor extent:           6.34 mm;   major extent:          3.17 deg.;
  area:              36.94 sq. mm;   relative amplitude:     0.87 %;
  min. distance to bore:   0.15 mm;   max. distance to bore:   4.42 mm;
  min. distance to ins.:  128.18 mm;   max. distance to ins.:  133.87
mm;
  axial start:          57.15 mm;   axial extent:           6.35 mm;
```

Figure 2. Example Token (left) and Corresponding Typed Anomaly (right).

Functional diagrams of the IS and PPA modules are shown in figures 3 and 4 respectively. Figure 3 shows a detailed

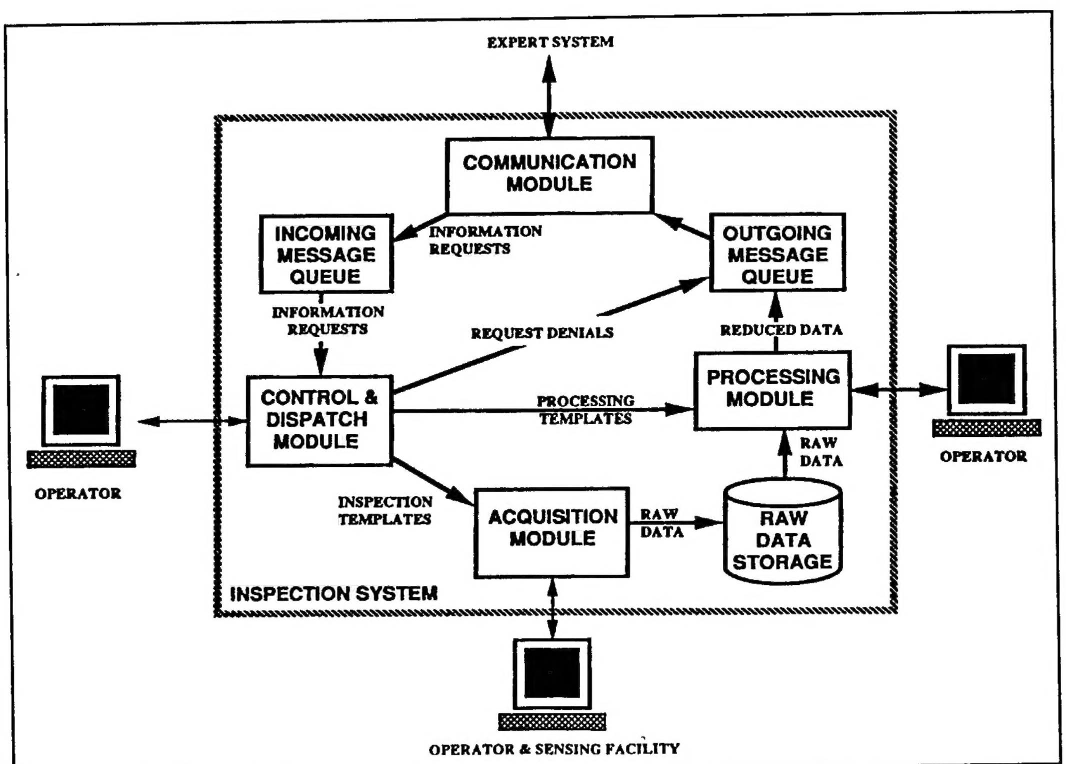

Figure 3. Functional Diagram of Inspection System Module.

functional diagram of the interior processes of the IS module as it was originally designed. The top three boxes in the figure represent the software features which would handle the internal functions for communicating with the rest of the ANDES system. The Control and Dispatch Module in the IS is the inspection system operator's interface for managing and scheduling the IS processes and for responding to system messages and requests. The Acquisition Module is the interface with the data acquisition system for the IS. The Processing Module is responsible for performing the image analysis and feature extraction from the NDE data. The Raw Data Storage is the location of the NDE data files generated by the acquisition system.

Looking at an operational scenario is the best way to clarify the functioning of the IS module. The production manager issues a message to the ANDES system requesting the normal thru-transmission ultrasonic inspection on motor serial number A-005 which is being transported to the ultrasonic facility. The ANDES system relays the message to the appropriate Inspection System module which places the request in the request queue, informing the operator of an inspection request. When the motor arrives, the operator mounts it in the inspection system and initiates thru-transmission data acquisition. When data acquisition is completed the data is stored in Raw Data Storage. The operator then issues a command to the IS to initiate data processing using the normal thru-transmission processing template. This template controls the actions of the Processing Module for retrieval of the raw data, feature extraction, token generation, and transmission of any token information generated to the ANDES data base. The IS module also issues two messages of its own. One goes to the originator of the data request informing him that the action is complete and the other goes to the decision system module of ANDES informing it that there is a set of anomaly tokens to be processed.

It was envisioned that a fully functional ANDES system would be integrated closely enough with the data acquisition systems, through the respective IS, that adaptive scan features would be available. This would mean that if the decision system modules of ANDES detected problems with the data or if there were difficulty processing anomalies from the token information, a request for a non-standard inspection could be issued automatically to the IS. This inspection request would contain the specifics of the inspection procedure to gather the additional data needed in order to properly assess the part. This request would be examined by the inspection system operator and he could either perform the requested operation or consult with the production manager to deny the request and instruct ANDES to use the existing data.

The largest module of the ANDES system is the Process / Product Analysis module. This module controls the main user interface for the system. The system management functions and much of the system setup and tailoring are also performed through this module. In addition, the PPA module performs the analysis and decision rendering functions on the tokens passed from the IS module. The functional diagram of the analysis and decision processes is shown in figure 4.

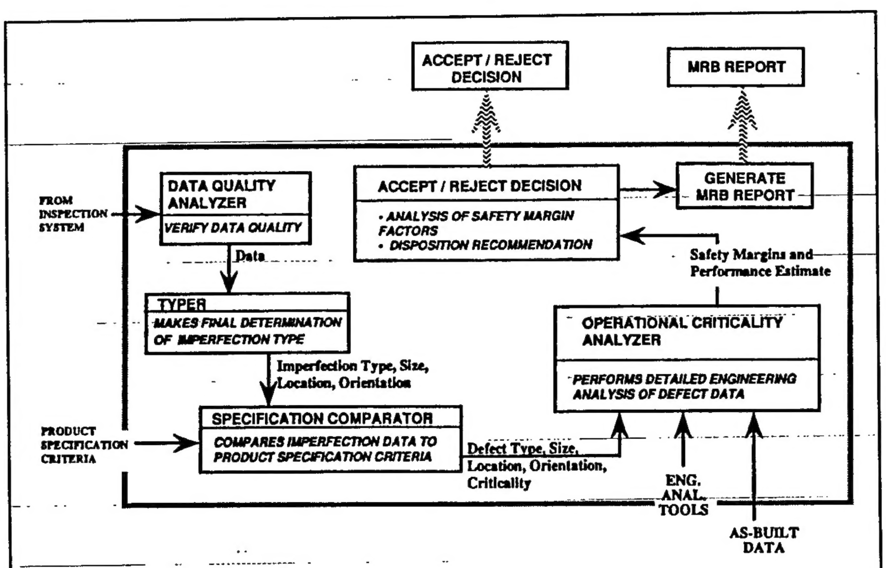

Figure 4. Analysis and Decision System Functional Diagram.

The PPA module periodically polls the message area of the ANDES data base for a message that a list of tokens has been generated by an IS module. When this message is detected, PPA retrieves the list of tokens and proceeds to process them using a template which has been designated by the operator. As shown in figure 4, the image and token data are received from the IS module. The image data would then be checked to verify the quality of the data. If the quality was sufficiently low, the PPA could issue a message to the IS requesting the data be replaced or permission to proceed with substandard quality. The token data describing each anomaly or feature in the NDE data would proceed to the Typer. In this step the token data is classified by type, size, orientation and location, see the example in figure 2. Once typed, the tokens are passed to the specification comparator which checks each anomaly against the appropriate product specification criteria. In this step each anomaly is categorized as being within or outside of tolerances. No further processing would be done on those anomalies that are within tolerances. They would simply be stored and reported. Anomalies exceeding the tolerances would be tagged as rejectable defects and would then be subjected to engineering analysis procedures built into the PPA module to estimate the remaining margin of safety and the projected impact on performance of the part. All of this information would then be passed to the final decision module to issue the recommended disposition of the part, accept or reject. If required, the system would then assemble a material review board (MRB) report to support the MRB process that would decide if the part could still be used with the lower margin of safety, if the part could be repaired, or if the part must be scrapped.

The data processing step which compares the typed anomaly information to product specifications is performed at three different levels. The first level is the single anomaly check. At this level each reported anomaly is checked against specifications for a single anomaly of the appropriate type. For example, if a void less than one half inch in diameter is acceptable, then any single void smaller than this is marked acceptable and the system proceeds to the next anomaly. Once all individual anomalies have been checked, the system then uses a nearest neighbor criteria to consider combined anomaly effects. In this check, the system is instructed that anomalies of similar type which fall within some threshold distance of one another are to be considered as a combined, larger anomaly. This combined anomaly condition is then checked against the established criteria. If the inspection data is two dimensional in form, such as an ultrasonics C-scan, the anomaly processing is now complete. If the data is three dimensional in nature, such as contiguous CT images, a third level of processing is used. For the case of CT images, the first two processing levels are performed on each CT image or slice. Once all slices have been processed individually, the system checks each anomaly in a slice for an adjoining anomaly in the next contiguous slice. In this manner anomalies which span several slices are identified and treated as a single anomaly. The slice spanning anomaly is then compared to the appropriate criteria to test for acceptability.

It is very important that the decisions the ANDES system would make could be traced and verified. Two methods were designed to provide this verification process. The first method was the institution of an audit trail of the anomaly processing. The user can display the acceptance criteria for any of the reported anomalies and the system will insert the corresponding values from the anomaly. In this way the user can determine which criteria controlled the accept / reject decision for the anomaly and what the actual value was of the anomaly characteristic which generated the decision. The second method, which was designed but not fully developed, is a data simulation module. This module would allow the operator to develop a realistic set of data containing anomalies using segments of actual data. In this way, the simulated data contained the characteristics of real data. The synthesized data sets with the user prescribed anomalies would then be fed to the ANDES system and processed. The results could then be compared to the known characteristics of the data to determine how the ANDES system was functioning.

4. SYSTEM FLEXIBILITY

It has been stated that the ANDES system was designed to be as generic and flexible as possible. The purpose was to create a system which could be applied to as broad a scope of products and processes as possible and to minimize the cost of tailoring the system to a specific application. The system was also designed to maintain several different processing configurations and allow the operator to select the configuration to be used from a menu. This capability would allow a single ANDES installation to service multiple production programs which use the same facilities for fabrication and inspection.

The core processes of the ANDES system are totally generic. These processes include the data base management system, the communication and messaging system, and the data analysis and decision processing engine. It is the peripheral processes and data handling which are unique to each application. The parts of the system which are unique include the interface to the individual data acquisition systems, the image analysis process which extracts the features from the NDE data, the specific anomalies and defects which are applicable to the inspected object, the specifications for the appropriate anomalies, and the contents of displayed or printed reports. ANDES employs two approaches to make the tailoring of these

unique processes much simpler by greatly reducing the amount of "hard code" which has to be written and compiled.

The first of these approaches is the use of an image processing system which executes user definable networks of standard and custom data processing modules. The overall ANDES configuration file contains the name of the image processing procedure to be used and the PPA passes this name to the IS when the request for data is issued. When the NDE data from the acquisition system is available, the IS issues the command to the image processing system to execute the procedure name received from the PPA. The image processing procedure contains the details about which image processing modules to use, in what order, what the input parameters are for the modules, and any other unique data that are required. This arrangement eliminates the need to make hard code changes in the main execution stream of the IS module to implement changes in the image processing. Any image processing code which must be written and compiled is limited to writing custom modules for networks executed by the image processing system. The networks themselves are generated using an interactive interface in the image processing system. Using this interface, assemblages of standard and custom modules can be hooked together to perform the necessary functions without modifying the IS or other ANDES system software. An example of a network of processing modules is shown in figure 5.

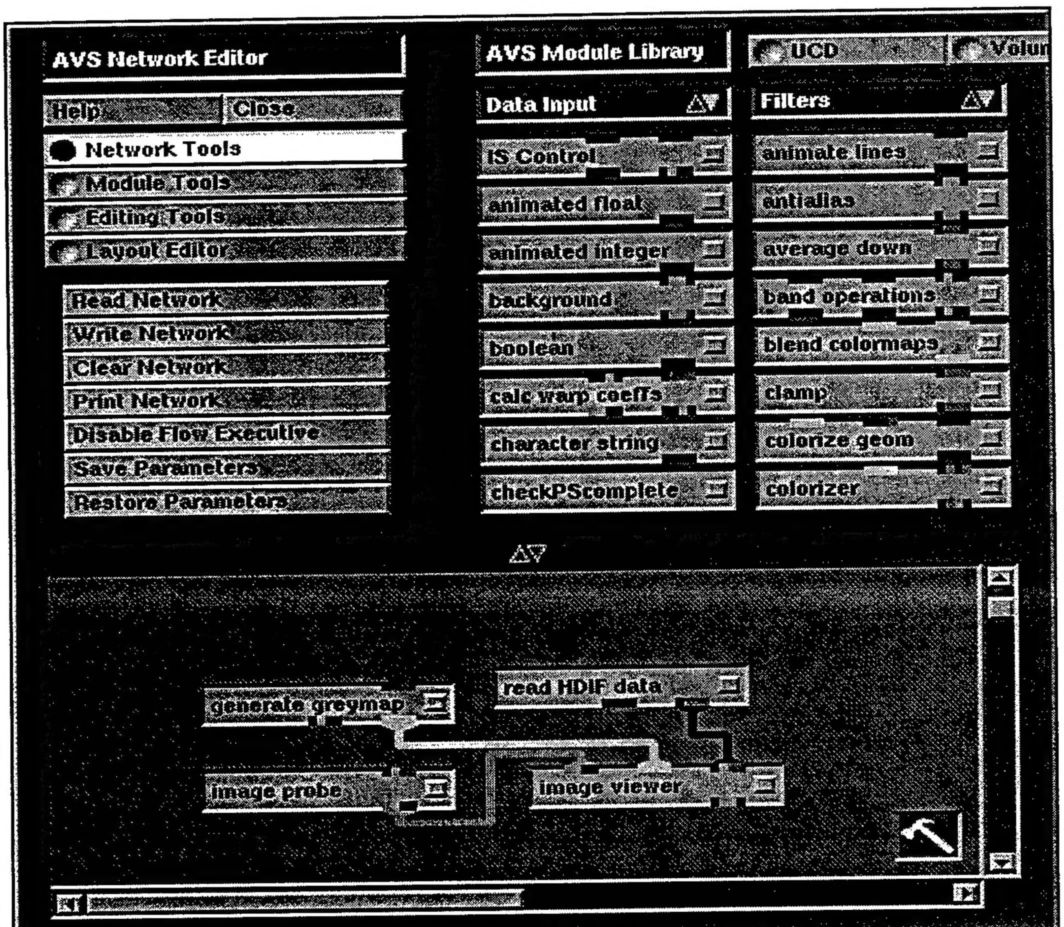

Figure 5. AVS User Workspace with Sample Network.

The second approach is the use of a script language interpreter to control and execute most of the processes in the analysis and decision system loop. The scripting language is patterned after the method described in the ADA Language Reference Manual, ANSI/MIL-STD-1815A-1983. This approach is very much like an interpreted BASIC language for desk top computers. Using the ANDES script editor window, the user writes text files which define the processing to be done. Parameter values describing the detected anomalies are retrieved from the anomaly tokens and processed by the script. The script then exports the results in the form of parameter values which are stored in the data base for use by subsequent

processes. The script can also initiate the execution of external programs, if needed, and retrieve results from the program when it is finished.

An example of a script is shown in figure 6. This script would be executed by the typer function to determine the type of a detected anomaly. The characteristics used by the typer script are stored in the token information for the anomaly. In the script shown in figure 6 there are ten input parameters which are retrieved from the token. These parameters are defined between the statements "external_variables:" and "end_external_variables;". These parameters consist of one text string and nine numbers. The purpose of the script is to establish the type of the anomaly so the only output value is a text string called "type". The main part of the script is a series of if-then-else logic statements which lead to various value for the anomaly type depending on the values of the input parameters. Similar scripts are used by the specification comparator and the operational criticality analyzer.

```
external variables:
in_text: class;
   in_number: rel_amplitude, major_extent_mm, major_extent_deg,
minor_extent_mm, axial_start, min_dist_to_bore, min_dist_to_ins,
orientation;
  out_text: type;
end_external_variables;

if (rel_amplitude >= 1.0) then
  type :="inclusion";

else_if (class = "propellant") then
   if ((major_extent_mm > 3) and
      ((major_extent_mm / minor_extent_mm) >= 2.0)) then
    if (rel_amplitude >= 0.65) then
      type := "liner wipe";

      else_if (((orientation > 80) or (orientation < -80)) and // parallel
        (min_dist_to_ins <=  5)) then
      type := "tear";
    else
      type := "crack";
    end_if
   else
     if (min_dist_to_bore < 1) then
       type := "gouge";      // or surface void, treated the same.
    else
      type := "void";
```

Figure 6. Excerpt from ANDES Typer Script.

5. OPERATIONAL SYSTEMS

The preceding paragraphs have described how the ANDES architecture was designed and how the system would have operated if the original four phases of the NDE for SRB's contract had been completed. Instead, the major software

development phases, phases three and four, of the original program were deleted due to loss of ALS funds and phases five and six were added to deliver operational systems to Kelly AFB and Hill AFB respectively. The system requirements for phases five and six were significantly less than for the ALS project. While the original ANDES hardware and software architectures were followed, a number of the features were not implemented in the operational systems. However, if there is a need, some or all of these features could be added at a later date. The tailoring of ANDES for each base consisted of some features which were common to both and other features which are unique. The common features will be described first. The unique features of each site will be discussed in separate sections.

Each ANDES installation at the two Air Force bases consist of two SUN workstations. In each installation, all of the ANDES hardware is located at the data acquisition site and services only one data acquisition system. The data acquisition system at each installation is X-ray CT. Due to the proximity of the ANDES systems to the data acquisition systems and the limited number of workstations, much of the message traffic was not implemented. In both cases, the operator of the acquisition system and the operator of ANDES is the same person, and notifications requesting inspection data from the PPA module to the IS module are not needed. Both sites are implemented using an object oriented data base and an image processing engine which employs user defined networks of standard and custom processing modules to perform the data analysis. Three of the processing blocks for the Process/Product Analysis module shown in figure 4 were not implemented in either system. These processing blocks are the data quality analyzer, operational criticality analyzer, and the report generator for MRB actions.

5.1 Kelly AFB system

Under the new phase five of the contract, a version of ANDES was developed and installed at Kelly AFB to assess several relatively small parts which were being inspected by the Kelly Science and Engineering Laboratory using X-ray CT. Schematic diagrams of these parts are shown in figure 7. The operational environment at Kelly AFB is that of a laboratory rather than a production facility. Their needs required that the image processing function of the ANDES system be much more flexible than a typical installation, so the IS "module" was in fact implemented as a stand-alone interactive process.

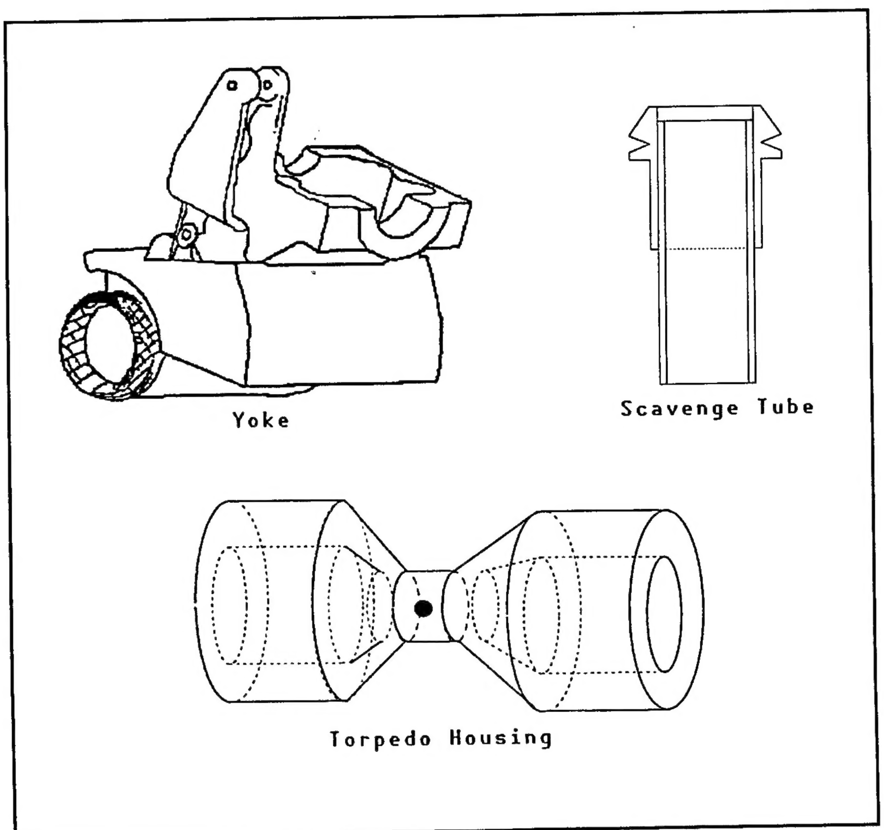

Figure 7. NN-ANDES Processed Components for Kelly AFB.

While it did interact with the ANDES system, it did so in a much more autonomous manner than would normally be the case. This IS was implemented using the KHOROS software system which is a public domain data visualization and processing environment. In addition, they were interested in evaluating the effectiveness of neural networks for performing the feature recognition tasks. Therefore, an additional stand-alone IS "module" was developed based on the Aspirin / Migraine neural network system. As a result of the neural net IS, this version of the software was named NN-ANDES.

A top level functional diagram of the NN-ANDES system at Kelly AFB is shown in figure 8. In the box on the far left side of the figure, SA-ALC stands for San Antonio Air Logistics Center. The CT system used at Kelly AFB is a 420 thousand electron volt system manufactured by Scientific Measurement Systems, SMS. The labeled arrows in the figure indicate the data or message flow between functions. The comments near the function boxes or oval indicate the tasks which are performed by the various functions.

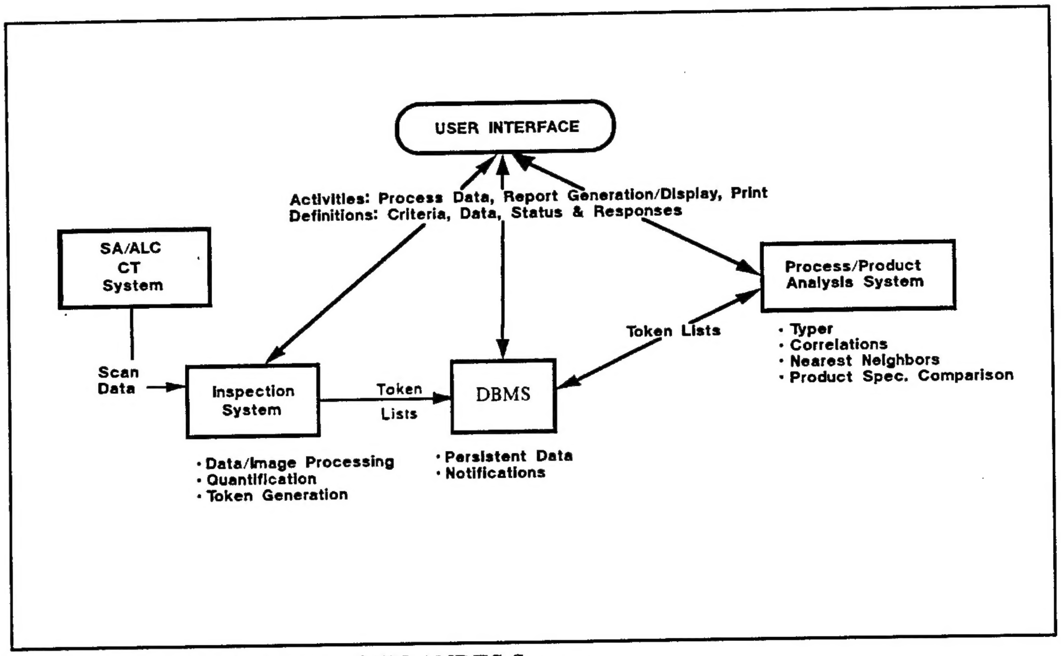

Figure 8. Functional Diagram of NN-ANDES System.

The requirement for a very flexible IS significantly increased the complexity of operating the system. The increased flexibility forced much more interaction by the operator than would normally be the case. The CT data acquisition and image reconstruction are controlled from the microVAX computer of the SMS CT system. The CT images are then stored on the microVAX's data disks. A stand-alone image file conversion program is then run to reformat the image data files in preparation for transfer to the SUN workstation. The operator then initiates the transfer of the image files via ethernet from the microVAX to the SUN. The next step is to process the images through the neural net IS or the KHOROS based IS to extract the information on possible anomalies and to generate the anomaly tokens. These tokens are automatically stored in the NN-ANDES data base. When the tokens are available, the operator initiates the PPA process which evaluates the tokens to identify actual defects and to compare the defects to the acceptance criteria. A report can then be generated and displayed for review or printed.

The data set for the scavenge tube consists of ten CT slices and represents 100 percent coverage of the braised area. The typical scan and image reconstruction time to acquire the data set is one hour. An additional one to one and a half hours is required to convert the image files and process them through the NN-ANDES system. The yoke casting required a custom scan plan for each part so there isn't a typical number of images in a data set. An average processing time for this part to acquire the necessary images, convert them into the SUN format and processes them through NN-ANDES is one and one half to two hours. The data set for the torpedo housing casting consisted of only three images. However, due to the size of the part, the data acquisition time is substantially greater. The total acquisition, conversion, image processing time for this

casting is about three hours.

The use of neural networks for processing the data at Kelly AFB did not prove very effective. The specific applications seemed not to lend themselves to this approach. Another big contributing factor was the lack of sufficient data sets which contained a sufficient number and mix of anomalies to properly train the neural networks. Although, it was and interesting approach, it was abandoned in favor of the more traditional capabilities of the KHOROS software.

5.2 Hill AFB system

The system installed at Hill AFB was tailored to support the inspection of Minuteman stage three rocket motors and has been named MM-ANDES. This system was greatly simplified in operation compared to the system at Kelly AFB. This was possible due to the well defined nature of the operation for Minuteman. A top level functional diagram of MM-ANDES is shown in figure 9. In the box on the far left side of the figure, OO-ALC stands for Ogden Air Logistics Center. The term ICT-1500 refers to the ARACOR ICT-1500, nine million electron volt CT system. The labeled arrows in the figure indicate the data or message flow between functions. The comments near the function boxes or oval indicate the tasks which are performed by the various functions.

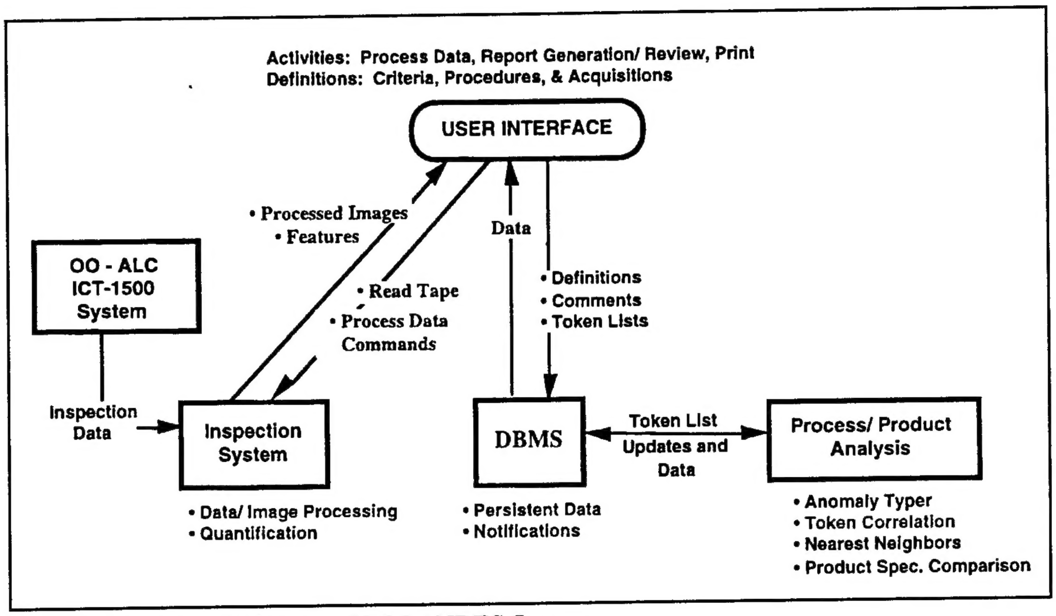

Figure 9. Functional Diagram of MM-ANDES System.

Figure 10 shows the hardware configuration and location of software for the MM-ANDES system. The box entitled SCATHA is the master workstation. This workstation houses the user interface, DBMS, and Process/Product Analysis functions shown in figure 9. MAGELLAN is the slave workstation in MM-ANDES. All of the IS functionality is located here. The remaining box in figure 10 depicts the ARACOR CT system. The controller for the CT operation is a VAX 11/750 computer. This computer controls all of the data acquisition and image reconstruction operations. It should be noted that there is not a direct connection between the CT system and MM-ANDES. The data transfer from the acquisition system to MM-ANDES is performed via nine track tape. This was necessary because the VAX computer in the acquisition system cannot communicate over an ethernet. In order for the VAX system to perform data acquisition and image reconstruction simultaneously, all processes not essential to those functions had to be eliminated from the VAX's operating system. This included the ethernet communication interface. Instead, the image data set is written to two tapes which are carried to the MM-ANDES system and read.

The operator uses SCATHA to initiate all MM-ANDES operations, including those performed on MAGELLAN. The operation can be described as a three "button" process, Read Tape, Process Data, and Review Report. The first step in the processing chain on MM-ANDES is to import the image data files from the CT system. The operator inserts the first of

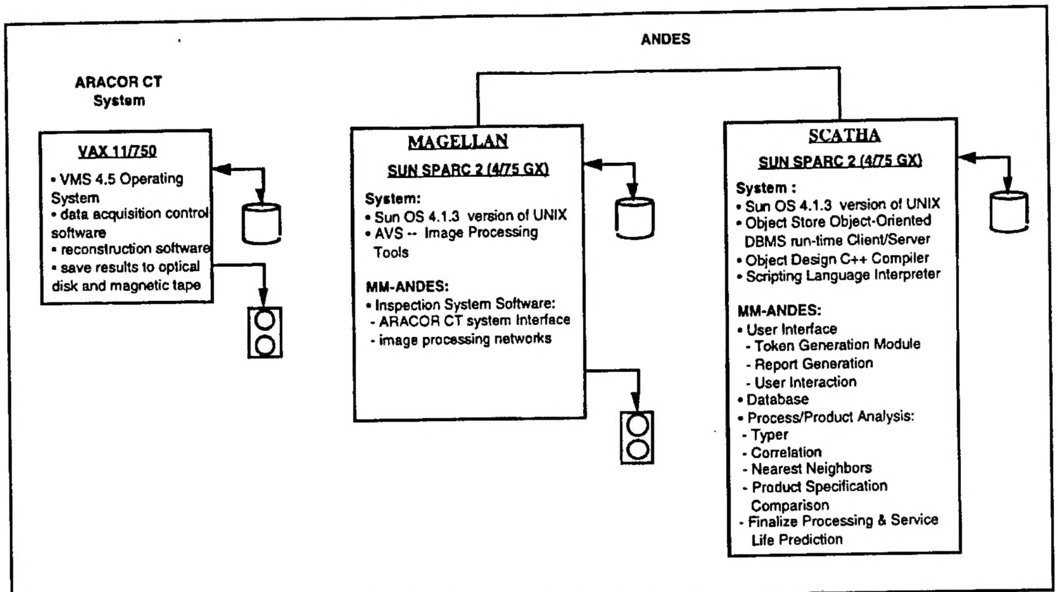

Figure 10. MM-ANDES Hardware and Software Configuration.

two tapes containing the image and label files into the MM-ANDES tape drive and selects the READ TAPE process from the menu in the main user interface. The user interface then issues a message to the inspection system module to read the tape in the tape drive. The IS reads the label file for the first image on the tape and extracts the information describing the motor. This information includes the motor type, motor serial number, and acquisition date. The data base is checked for an existing entry for the motor type and serial number. If there is no existing entry for this motor, one is generated. The data base is then checked for an existing entry for the acquisition date. If one exists, in other words, the data set is being reprocessed, the old results will be overwritten. More likely, a new entry is created for the acquisition date of the data set being imported. The IS also generates a subdirectory named as the acquisition date in the processed data directory. After the image files have been processed they are moved from the raw data directory to the processed data directory. Having initialized the system data base and created the necessary file directories , the IS proceeds to read in all images on the tape, convert the image and label file for each CT slice into a single file, and store the converted files in the raw data directory. When the end of the tape is reached, a message is displayed on the main interface terminal informing the operator that the reading of the tape has been completed. If there are any more tapes to be read, the operator loads the next tape and starts the reading process again.

The next step in the processing chain is the analysis of each CT image to extract features which may be anomalies. The operator opens the process data window from the user interface, and from a list of available data sets, selects the data set to be processed. The user interface scans the raw data storage for all image files with the selected serial number and acquisition date and generates a "process image" message on each one for the IS. This message contains the motor serial number, acquisition date, and the slice number. The message also includes the image processing procedure to be used. The IS retrieves a process image message from the message queue, searches the raw data directory for the image file, and initiates the execution of the image processing procedure identified in the message. When the image processing is finished, the IS writes all tokens which were generated to the front of the image data file, moves the image file to the processed data directory, and informs the PPA that a token list is available for this CT slice. The IS then retrieves the next process image message and repeats the cycle until all the messages are gone.

The image processing tasks in the MM-ANDES IS were implemented using the commercial AVS software produced by Advanced Visual Systems, Inc. This software operates similar to KHOROS in that it is a processing framework that executes networks of standard and custom processing modules which perform the various tasks for image analysis. The "process image" message which the PPA sends to the IS includes the name of the specific network to use for the processing of the slice number indicated in the message. For the MM-ANDES installation, all slices were processed by the same network. However, this network references a user developed text file of configuration information which describes the unique processing requirements for various zones in the motor geometry. The network then chooses appropriate branches in the processing stream to execute based on this configuration file. In this manner, each individual CT image is processed by the most appropriate image analysis methodology.

The PPA module retrieves the "token list available" message from the message queue, retrieves the image file name, and proceeds to process the tokens found by the IS. There are two passes made on the tokens in order to complete the processing. The first pass is to process all tokens for a single CT slice. Each token is examined to determine if it is an anomaly or a known motor feature based on a priori knowledge of the motor geometry. True anomalies are then typed and compared to the single flaw acceptance criteria for the anomaly type. Once all anomalies in the slice have been processed, all anomalies of the same type are checked against the nearest neighbor specifications. Specifications are given to the PPA defining the threshold distance for an anomaly type which states that two flaws of the same type nearer each other than the threshold distance will be treated as a single, larger anomaly. Once all nearest neighbors have been identified and tokens are generated describing the combined anomaly, these new tokens are compared against the appropriate criteria for acceptance.

Once all slices have been processed by the PPA in the first pass, the operator initiates the final processing pass. In this step, all anomalies in a slice are examined to determine if there is an anomaly of the same type at the same location (within some user defined threshold tolerance) in a contiguous slice. At the end of this processing pass, any anomaly which spans two or more CT slices will have been identified and compared against the appropriate criteria for acceptance. It is necessary for the operator to initiate this processing step because the system has no way of knowing if all the data set images were in the raw data directory prior to starting the single slice processing pass. It is possible that additional images were acquired and loaded into the MM-ANDES system after the single slice processing was started. Therefore, the system must be told when to perform the tests for slice spanning anomalies.

The final step in the processing chain is the generation of a report of the analysis results. The operator may request the system generate and display a report of the results at any time during the token processing or after all processing has been completed. The operator selects the review report process from the user interface and selects from the list of available serial numbers and acquisition dates the specific report desired. This report is displayed to the screen for review by the operator. Non-erasable comments may be added to the report by the operator as needed. When desired, a paper copy of the report can be printed.

The third stage data set consists of 120 image files and an equal number of label files. Two tapes are required to transport the data set to MM-ANDES. A total of forty minutes is required for the IS to input the data set from tapes. The image processing takes six to seven hours. The time varies based upon the number of reconstruction artifacts and general quality of the images and upon the total number of anomalies detected. Once all CT slices in a data set have been processed, the check for slice spanning anomalies is performed. This process takes another one or two minutes.

6. SUMMARY

The system at Hill AFB has been in service for more than a year; the one at Kelly AFB more than two years. The reports from Kelly AFB have all been positive. No problems with the functioning or decision making of the system were reported. Due to the closure of the San Antonio Air Logistics Center, the workload for the NN-ANDES system did not materialize as expected and the system is now inactive. The reports on the MM-ANDES system at Hill AFB have also been positive. A significant number of data sets have now been processed by the MM-ANDES system. One software bug was discovered in a non critical function of the system and has been eliminated. This bug involved the automatic data base preparation by the read tape function when it attempted to process a second set of data (new acquisition date) for an existing motor serial number. The problem was easily circumvented by preparing the new entry in the data base manually, but the error in the software has since been corrected. The bug did not affect the image analysis, defect detection, or decision making processes of the system. A few other operation related "glitches" have been encountered, but these have involved inconsistences in the data files generated on the data acquisition system and not software problems with MM-ANDES.

The Air Force and NASA initiated the NDE for Solid Rocket Boosters program in 1989 to develop an automated system for processing NDE data. Although the original focus of the effort was changed due to changes in National priorities, much of the intent of the effort was never-the-less achieved with the delivery of the two operational systems to Kelly AFB and Hill AFB. The successful use of automated decision making on digital NDE data has been demonstrated. The original hardware and software architectures have proved to be very successful demonstrating the intended design flexibility for tailoring to dissimilar applications without major overhauls to the core software.